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CHARACTERIZATION AND PROPERTIES OF BAMBOO ASH REPLACEMENT IN FLY ASH BASED GEOPOLYMER CONCRETE

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CHARACTERIZATION AND PROPERTIES OF BAMBOO ASH REPLACEMENT IN FLY ASH BASED GEOPOLYMER CONCRETE

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DEDICATION

Praise be to Allah s.w.t, the Lord of the Worlds

Who says (interpretation of the meaning):

"Give thanks to Me and to your parents. Unto Me is the final destination"

[Quraan, Luqmaan 31:14]

All glory and honor to Him

To my parents

Noorizah binti Osman and Ishak bin Ahmad

To my greatest supporters

Shazry, Sharmine, Shameera, Nurul Suhada and Ayden Syah

And also to all who supported me by Doa and work.

Thanks for everything.

May Allah bless you.

Amin

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ABSTRAK

Malaysia, sebagai negara hutan hujan tropika, menikmati banyak tumbuhan buluh yang meluas di seluruh negara. Penggunaan teknologi geopolimer telah menjadi fenomena selain dapat memelihara alam sekitar dari bahaya. Geopolimer abu terbang memiliki kekuatan awal yang rendah dan memerlukan 24 jam untuk konkrit mengeras. Oleh itu, kehadiran kalsium dan kandungan kalium dalam abu buluh dapat memperbaiki masalah ini. Tiada kajian mengenai penggunaan abu buluh sebagai pengikat dalam konkrit geopolimer. Oleh itu, kehadiran abu buluh dapat meningkatkan lapangan penyelidikan dengan penggunaan sisa pertanian dalam pembinaan bangunan. Matlamat penyelidikan ini adalah menggunakan abu buluh dalam pengeluaran konkrit geopolimer abu terbang. Spesimen telah dikeraskan dalam 100mm x 100mm x 100mm kiub dan pengaktif berasaskan natrium digunakan sebagai cecair alkali. Pengikat digubal dengan nisbah pengikat yang berbeza dan cecair kepada nisbah pengikat. Semua spesimen ujian telah dirawat pada suhu ambien (23°C -25°C) dan 100% abu terbang dipilih sebagai spesimen kawalan. Bagi kajian awalan bancuhan konkrit, 3 ujian dijalankan, iaitu ujian pengerasan konkrit, ujian aliran dan ujian geopolimerisasi. Untuk sifat-sifat pengerasan, 10 eksperimen yang berbeza telah diuji iaitu kekuatan mampatan, kekuatan lenturan, kekuatan tegangan, modulus keanjalan, halaju nadi ultrasonik, penyerapan air, ketumpatan, pengecutan pengeringan dan pengembangan haba dalam suhu tinggi. Akhir sekali, analisis fasa dan analisis mikro dilakukan selama 7 hari dan 28 hari umur rawatan. Hasil ujian menunjukkan bahawa sebagai peratusan abu bulu berkurangan, kekuatan mampatan bertambah. Selain itu, penambahan 5% abu buluh ke dalam konkrit geopolimer abu terbang dapat meningkatkan kekuatan awal dalam 7 hari. Hasilnya terbukti dengan analisis fasa yang menjelaskan keberkesanan pembentukan natrium aluminat silikat hidrat (NASH) dan kalsium aluminat silikat hidrat (CASH) untuk kekuatan matriks geopolimer. Selain itu, penambahan 5% abu buluh mengurangkan masa pengerasan konkrit geopolimer abu terbang sebanyak 40%. Penambahan abu buluh meningkatkan kekuatan tegangan dan juga kekuatan mampatan apabila terdedah kepada suhu tinggi 800°C. Oleh itu, dapat disimpulkan bahawa penambahan abu buluh meningkatkan kekuatan awal, tempoh pengerasan, kekuatan tegangan dan kekuatan mampatan apabila terdedah kepada suhu tinggi.

ABSTRACT

Malaysia, as a tropical rainforest country, enjoys an abundance of bamboo plant that proliferate throughout the country. The application of geopolymer technology has become a trend and preserves the environment from harm. Fly ash geopolymer concrete has low early strength and requires 24 hours for the concrete to harden. Thus, the presence of calcium and potassium content in bamboo ash could remedy this problem. Besides, there is no research regarding the use of bamboo ash as a binder in geopolymer concrete. Therefore, the presence of bamboo ash could improve the research field with the use of agriculture waste in a building construction. The research aim is to use bamboo ash in the production of fly ash geopolymer concrete. The specimens were casted in 100mm x 100mm x 100mm cubes and sodium based activator were used as the alkaline solutions. The binders are formulated with different binder ratio and solution to binder ratio. All test specimens were cured at ambient temperature (23°C -25°C) and 100% fly ash was chosen as control specimen. For fresh state properties, 3 tests were conducted, which are setting time, flow table and geopolymerization test. For hardened state properties, 10 different experiments were tested which are compressive strength, flexural strength, splitting tensile strength, modulus of elasticity, ultrasonic pulse velocity, water absorption, density, drying shrinkage, thermal expansion and elevated temperature. Lastly, phase analysis and microstructure analysis were conducted for 7 days and 28 days of curing age. The test results depicted that as the percentage of bamboo ash decreases, compressive strength increases. Also, the addition of 5% of bamboo ash into fly ash geopolymer concrete could improve the early strength in 7 days. The results were proven with the phase analysis that explains the effectiveness of the formation of sodium aluminate silicate hydrate (NASH) and calcium aluminate silicate hydrate (CASH) for the strength of geopolymer matrix. Furthermore, addition of 5% of bamboo ash reduced the setting time of fly ash geopolymer concrete by 40%. The addition of bamboo ash improved tensile strength and also compressive strength when exposed to elevated temperature of 800°C. Therefore, it can be concluded that the addition of bamboo ash improved the early strength, setting time, tensile strength and compressive strength when exposed to high temperature.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BS	-	British Standard
CASH	-	Calcium Aluminatesilicate Hydrate
NASH	-	Sodium Aluminatesilicate Hydrate
PSA	-	Particle Size Analysis
XRF	-	X-Ray Fluorescence
XRD	-	X-Ray Diffraction
SEM	-	Scanning Electron Microscopy
EDX	-	Energy Dispersive X-Ray
UPV	-	Ultrasonic Pulse Velocity
CTE	-	Coefficient of Thermal Expansion
CO_2	-	Carbon Dioxide
SiO_4	-	Silicate
AlO_4	-	Aluminate
NaOH	-	Sodium Hydroxide
Na_2SiO_3	-	Sodium Silicate
SP	-	Superplasticizer
BA	-	Bamboo Ash
FA	-	Fly Ash
POFA	-	Palm Oil Fuel Ash
RHA	-	Rice Husk Ash
OPC	-	Ordinary Portland Cement
GGBS	-	Ground Granulated Blast Furnace Slag
U.N. FAO	-	Food and Agriculture Organization of the United Nations
OD	-	Oven-Dried
SSD	-	Saturated-Surface Dry

LIST OF SYMBOLS

M	-	Bulk Density of Aggregates
F_C	-	Compressive Strength
R	-	Flexural Strength
Fct	-	Splitting Tensile Strength
σc	-	Compressive Strength of Cylindrical
Ec	-	Modulus of Elasticity
V	-	UPV value
T	-	Density
ε	-	Strain

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Production of Portland cement consumes considerable energy while providing a massive volume of carbon dioxide (CO_2) to the atmosphere. This conventional binder in concrete has performed exceedingly well in most civil engineering applications (Rajamane *et al.*, 2012) but its production contributes to the emission of greenhouse gas of CO_2. In addition, concrete produced with Portland cement is less durable in some of the aggressive environment conditions (Neville, 2011). Over time, geopolymers have become a problem solver to all these issues (Duxson *et al.,* 2007). High demand of conventional concrete leads to high emission of carbon dioxide to the atmosphere. Thus, using geopolymer concrete which is known as an environmental friendly concrete, can solve landfills problems by recycling and reusing waste materials. The best option to eliminate these problems is by utilizing the waste for construction purposes. Using waste products as a cementitious material in geopolymer concrete would also maximize its recycling potentials throughout the industrial sector.

Geopolymer is an organic polymeric composite that is hardened at ambient temperature under highly alkaline conditions (Davidovits, 1994). Alumina silicates are dissolved and free element (SiO_4 and AlO_4) of tetrahedral units are moving randomly, known as geopolymerization. Apart from that, geopolymer concrete has superb resistance to chemical attack and show great ability against the aggressive environment. Aggressive marine environments, surroundings with enormous percentage of carbon dioxide, high content of sulphate and acidity in soils are particularly applicable (Rangan, 2014).

Interest the using of fly ash as sustainable materials in geopolymer concrete has increased since 2000 (Dhananjay and Vikrant, 2015). The development of geopolymer concrete mix design has been successfully done in Australia (Curtin University and Western Australia). Hardjito and Rangan (2005) investigated the effects such as alkaline parameters, water content and curing conditions in their research. In Malaysia, some researchers focused on geopolymer concrete (Nuruddin *et al.*, 2014; Azreen *et al*., 2015). Eventually, geopolymer topic has become prominent among researchers because of its environmentally friendly and high performance aspects.

Agriculture waste is a serious environmental problem in many countries. These waste was dominantly produced from garden and rice fields. Concerning the ecological sustainability, the importance of recycling, finding economical fruit by-products is one important approach to protecting the environment. The majority of previous research involving agriculture waste consist of Palm Oil Fuel Ash (POFA) (Abdul and Abubakar, 2011; Yong *et al.,* 2014; Ahmad Hussein *et al.,* 2017) and Rice Husk Ash (RHA) (Habeeb and Mahmud, 2010; Kartini and Ir, 2011; Kawabata *et al.,* 2012) as binder.

Interest in bamboo for construction grows continuously as focus shifts towards reducing the environment impact and embodied energy of the built environment. Naturally, the form of bamboo is cylindrical pole or culm. Bamboo is also part of the grass family. There are over 1200 species of bamboo all over the world, with structural species varying by location. The different species can be categorized into three types of root systems, sympodial (clumping), monopodial (running) and amphipodial (clumping and running). According to Food and Agriculture Organization of the

United Nations (U.N. FAO), a total of 72% of land area in Malaysia is filled with forests; 42 000 km^2 is filled with tree plantations. Bamboo is an easy growing plant. Tropical rainforest such as that found in Malaysia provide ideal growing conditions for the bamboo plant. The production of bamboo charcoal has increased and its application especially in healthcare, cooking, water purification and gardening have grown significantly (Mingjie, 2004). Consequently, bamboo ash is the waste from the production of bamboo charcoal. Although rich in silica, the poor performance of bamboo ash as a sole aluminasilicate material for geopolymer synthesis due to low alumina content has made it attractive for combination with other material rich in alumina such as fly ash.

Unfortunately, literature about bamboo ash as aluminasilicate materials in geopolymer concrete are unavailable. Thus, this research is conducted to fill this gap for the development, manufacturing and engineering properties of bamboo ash replacement in fly ash based geopolymer concrete.

1.2 Problem Statement

Production of fly ash geopolymer concrete gives high strength and durability. However, the setting time performance was disappointing. According to Ramujee (2016), fly ash geopolymer concrete requires 24 hours to harden and the duration is not suitable for certain type of construction works (Srinivasan and Sivakumar, 2013). Nevertheless, a material with calcium content can improve the setting time and the addition of calcium content in bamboo ash could remedy these problem.

According to previous research (Nath *et al.*, 2015), fly ash geopolymer concrete bothering on the low early strength to exaggerate the geopolymerization process. Bamboo ash has unique speciality where it contains high percentage of potassium. The presence of high potassium in bamboo ash can contribute to the formation of early ettringite, thus producing a better early strength (Huynh and Laefer, 2009). This advantage was believed to contribute to the early strength of fly ash geopolymer concrete.

No information from the previous study regarding the utilization of bamboo ash in geopolymer concrete is available. In addition, there is no research on the replacement of bamboo ash into fly ash geopolymer concrete. Most of the researchers only focuses onto well-known agriculture waste such as rice husk ash (RHA) and palm oil fuel ash (POFA). Besides, bamboo ash was believed can contribute on setting time and early strength of geopolymer concrete with the presence of calcium and potassium content. This strongly indicates important gaps to be filled in the process of development of an efficient fly ash geopolymer concrete with the replacement of bamboo ash for practical construction purposes.

1.3 Research Objectives

The aim of this study is to investigate the characterization and properties of bamboo ash replacement in fly ash based geopolymer concrete. A number of objectives are highlighted to guarantee all the fundamental parameters are achieved.

1. To investigate the characteristics and appropriate mix design of fly ash geopolymer concrete with bamboo ash replacement.

2. To determine the physical and mechanical properties of geopolymer concrete using a combination of bamboo ash and fly ash.

3. To study the effect of bamboo ash and fly ash on the microstructure and phase analysis of the geopolymer concrete.

1.4 Scope of Research

In this study, bamboo ash and fly ash are the binder in geopolymer concrete. As a new material, bamboo ash needed to undergo a few processes before being used in the mix. Test such as physical analysis, chemical composition analysis, phase analysis and microstructure analysis are identified for both materials. Then, bamboo ash were added in ratio of 0%, 5%, 10%, 15% and 20% as fly ash replacement.

Next, the proportion is formulated with different solution to binder ratio which is 0.40, 0.45 and 0.50. However, for fresh state properties, several tests were conducted which are setting time, flow table and geopolymerization process test. For hardened state properties, 10 experiment were conducted to determine compressive strength, flexural strength, splitting tensile strength, modulus of elasticity, ultrasonic pulse velocity, water absorption, density, drying shrinkage, thermal expansion and elevated temperature. For comparison purposes, fly ash geopolymer concrete was used as control specimens. Also, phase analysis and microstructure analysis were conducted for 7 days and 28 days of curing ages. All specimens were casted into 100mm x 100mm x 100mm cube size and cured at ambient temperature (23 °C -25 °C).

1.5 Significance of Study

One of the problems associated with the established geopolymer concrete, which is fly ash, is the high setting time and low early strength. Therefore, by adding new material, which is bamboo ash, with calcium and potassium content will reduce the setting time and improve early strength of fly ash based geopolymer concrete. Thus, it is suitable to use in construction with ambient temperature for curing purposes.

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